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TECHNICAL REPORT 1765
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Automating the Acoustic Monitoring of New Zealand Waters for Migrating Humpback Whales (*Megaptera novaeangliae*)

D. A. Helweg

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San Diego, California 92152–5001

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ADMINISTRATIVE INFORMATION

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Marine Mammal
Research Branch

Under authority of
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Biosciences Division

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EXECUTIVE SUMMARY

Historically, some Southern Hemisphere Area V (130°E to 170°W) humpback whales (*Megaptera novaeangliae*) migrated from Antarctic feeding sites to wintering sites off eastern Australia and the southwestern Pacific through New Zealand waters. During winter months, males appear to advertise their presence by producing lengthy, loud songs, and the presence of singing whales is a reliable indicator of a migratory route. Today, humpbacks are sighted only occasionally in New Zealand waters. Because the number of humpback whales passing through New Zealand waters is extremely low, the probability of visual encounters is limited relative to the probability of acoustic detection, at least for singers. In this study I describe the results of acoustic monitoring of New Zealand waters for the presence of singing humpback whales. A low-cost, off-the-shelf computer system and shareware was used to automate the monitoring process. Recordings were made every day from 18 July through 11 December 1995, and 22 May through 7 October 1996, with the assistance of the Royal New Zealand Navy (RNZN) Great Barrier Island Sound Range Facility, using a permanent hydrophone fixed to the bottom in approximately 75 m of water approximately 2.5 km east off Great Barrier Island, New Zealand. Custom software sampled the continuous input from the hydrophone for 5 minutes every 90 minutes, around-the-clock, thereby creating an "acoustic net" to "catch" singing whales. A total of 147 days were monitored from 18 July through 11 December 1995, and 117 days from 22 May through 7 October 1996. Samples were scanned aurally for humpback whale vocalizations by the author. No singing humpback whales were heard in either year throughout the sampling period. However, a 5-sec FM downsweep from 50 to 22 Hz was heard in both years, identical to that reported by Kibblewhite et al. in 1967. More than 14,000 of these calls were detected, extracted, and measured using a simple replicate correlator in real time. Although the species is unknown, the joint time-frequency structure of these calls is very similar to blue whale "D" calls reported in coastal North Pacific waters. The replicate correlator allowed detection of the stereotypical LF whale call with high accuracy and low false alarm rates, even in very poor signal-to-noise conditions. Other baleen whale vocalizations, such as blue whale "A" and "B" calls and fin whale pulses are stereotypical and can be detected and logged using matched filters. Acoustic monitoring of whale abundance and distribution is a viable methodology that is not as limited by weather, light, or mobility conditions as are vessel transect surveys. Such acoustic survey research will complement studies of populations and species of cetaceans wherever acoustic assets are available, and is a necessary step in developing a long-term monitoring program for endangered and threatened marine mammals. The automated scan sampling and call detection techniques described may be integrated and applied to monitoring for vocalizing whales in future studies.

CONTENTS

Figures

INTRODUCTION

In the austral fall, humpback whales (*Megaptera novaeangliae*) in Southern Hemisphere Area V (130°E to 170°W) migrate from Antarctic feeding sites to wintering sites off eastern Australia and the southwestern Pacific. Historically, some Area V whales migrated through New Zealand waters (Chittleborough, 1965; Dawbin, 1966). Peak migration formerly occurred from mid-June through mid-July (Dawbin, 1966). During winter months, males appear to advertise their presence by producing lengthy, loud songs, and the presence of singing whales is a reliable indicator of a migratory route. Today, humpbacks are sighted only occasionally in New Zealand waters, occurring in the austral autumn as the whales migrate northward and in the austral spring when they are returning to Antarctic waters (Helweg et al., 1998).

Activity related to reproduction occurs in low-latitude tropical and near-tropical winter regions. Males appear to advertise their presence by producing complex songs that consist of circular sequences of themes constructed from nested sets of sound units (Payne & McVay, 1971). A full song theme cycle lasts approximately 8 to 12 minutes, but bouts of singing typically last for hours (Helweg et al., 1992; Payne & McVay, 1971). Source levels for song units have exceeded 180 dB (re 1 μPa at 1 m), but average levels were closer to 155 dB (Levenson, 1972). The function of song remains unknown, but the minimal conclusion is that song plays some role in the reproductive success of male humpbacks (Helweg et al., 1992).

Singing peaks in winter months (Thompson & Friedl, 1982), but can be heard in migratory waters (Cato, 1991; Clapham & Mattila, 1990; Helweg et al., 1998; Tyack & Whitehead, 1983) and occasionally in high-latitude summer waters (Mattila et al., 1987; McSweeney et al., 1989). The presence of singing whales is a reliable indicator of a migratory route (Cato, 1991; Clapham & Mattila, 1990). Kibblewhite, Denham and Barnes (1967) described the near-continuous presence of "a barnyard chorus" of sounds observed using Royal New Zealand Navy (RNZN) assets off Great Barrier Island, New Zealand. Figure 1 shows the location of Great Barrier Island. Contemporary analysis of recordings from this period revealed this chorus to be humpback whale song (Helweg, personal observation). Some song samples were of very high quality, and the observed song structure was well developed, but abbreviated, similar to that reported for song in higher latitude migratory waters. In New Zealand, migratory singing was commonly heard off Great Barrier until approximately 1965 (Kibblewhite et al., 1967). No singing was heard off Great Barrier in the latter 1960s, which coincides with the crash of Southern Hemisphere baleen whale stocks in the early 1960s (Chittleborough, 1965; Paterson & Paterson, 1989).

Although Paterson and Paterson (1989) suggested an increase in the number of eastern Australian humpback whales, recovery of that portion of the Group V stock that formerly migrated past the New Zealand coast has not been detected. Because the number of humpback whales passing through New Zealand waters is low, the probability of visual encounters is limited relative to the probability of acoustic detection, at least for singers (e.g., Cato, 1991). The recording of a singing humpback whale in Kaikoura, New Zealand in 1994 (Helweg et al., 1998) spurred renewed interest in the use of acoustic assets to monitor for migrating humpbacks.

In this report, I describe the results of an initial study using acoustic monitoring of New Zealand waters for the presence of singing humpback whales. The high source levels and multi-hour duration of song bouts makes this vocalization amenable to detection by scan sampling. The RNZN listening assets used by Kibblewhite et al. (1967) remain functional, serendipitously placed in the traditional New Zealand migratory route. Based on reliable observations of singing detected with this hydrophone, an automated system was deployed in 1995 and 1996 to "catch" migrating humpback whales with an "acoustic net." The purpose of this paper is to (1) describe the automated system for monitoring and analysis of recordings, and (2) describe the results of these analyses. A serendipitous finding of low-frequency calls matching those described by Kibblewhite et al. (1967), and the automation of the detection process, will also be described.

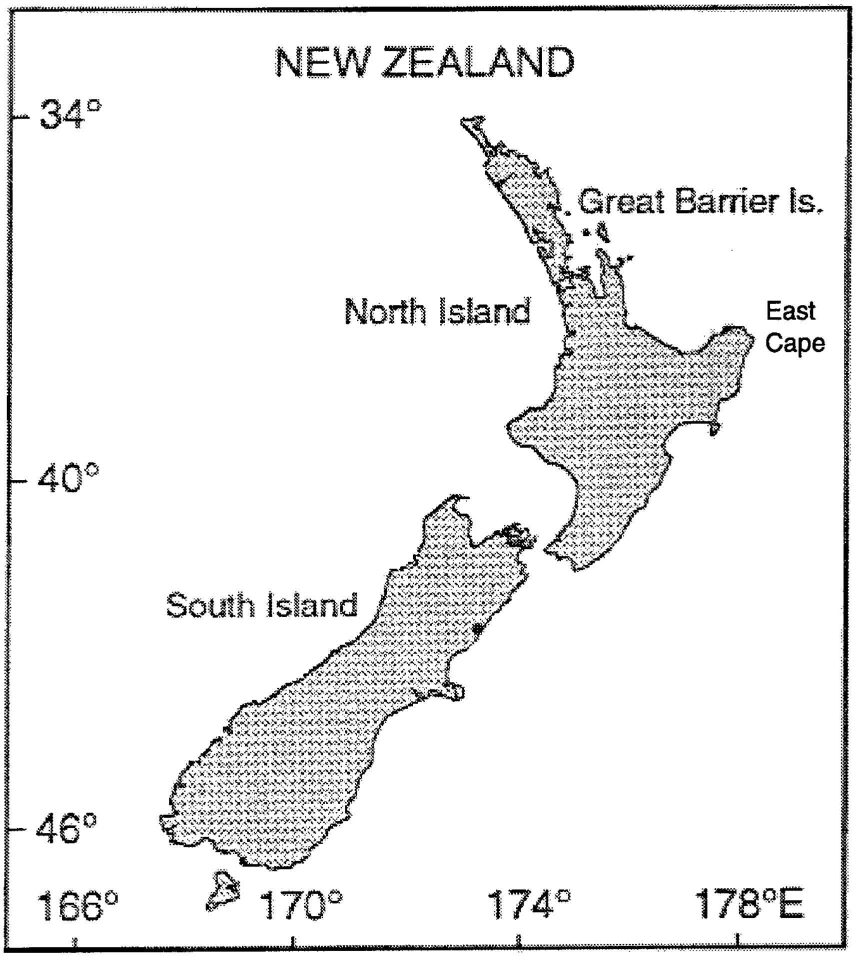

Figure 1. Study region. Note that Great Barrier Island is in direct line with East Cape, where blue whales were sighted during the study period.

METHODS

DATES AND LOCATIONS

Recordings were made every day from 18 July through 11 December 1995, and 22 May through 7 October 1996, with the assistance of the Royal New Zealand Navy (RNZN) Great Barrier Island Sound Range Facility (see figure 1). The ocean was monitored for singing humpback whales with a permanent hydrophone approximately 2.5 km east off Great Barrier Island (GBI), fixed to the bottom in approximately 75 meters of water.

EQUIPMENT

Underwater sound was monitored continuously using a permanently fixed, bottom-mounted hydrophone (RNZN). Samples were digitized and streamed to computer files using a CreativeSounds SoundBlaster 16-bit card mounted in an IBM-compatible PC. The SoundBlaster was driven using Pascal shareware subroutines written by Ethan Brodsky, downloaded at the following World Wide Web address:

"http://www.xraylith.wisc.edu/%7Eebrodsky/sb16doc/sb16doc.html".

The process was automated using a simple Pascal executable called in the PC AUTOEXEC sequence. This code is presented in appendix A. Data were stored to magnetic tape using a Conner 500 MB, 8-mm tape drive, with backup automated using software provided by Conner. Samples were restored to disk and scanned for cetacean sounds using the SoundBlaster card, Brodsky shareware, and custom software written in LabView.

SCAN SAMPLING PROCEDURES

The scan sampling protocol can be conceived of as an acoustic net. Custom software sampled the continuous input from the hydrophone for 5 minutes every 90 minutes, around-the-clock. This resulted in 16 5-minute sample files per day. The software automatically moved the files to magnetic tape once per day and cued the GBI staff to change the tape once a week. Samples were scanned aurally for humpback whale vocalizations by an expert system (the author). To expedite data throughput, tapes were scanned at 11 Hz, approximately double the sampling rate.

REPLICATE CORRELATION PROCEDURES

Low-frequency vocalizations were extracted from recordings made at 256 Hz, 24 hours per day throughout 1995 and 1996. These recordings were made in parallel to the 5-kHz scan samples using identical hardware and software configurations. Sampling dates were identified using the 5-kHz scan samples. Vocalizations were detected, extracted, and measured using a simple replicate correlator. Figure 2 shows the replicate waveform. Digital data were passed through the filter. Detection threshold was a correlation peak greater than 0.5. When threshold was exceeded, the algorithm remained triggered until the correlation fell below threshold. The time of peak correlation was used to center a sampling window of 2048 points, which was large enough to contain the full duration of the LF call. Every sample was stored to file. Also, the date, time, received level (dB re 1 μPa at 1 m), duration, and fundamental frequency contour were stored to a separate file. Duration was estimated from the leading and trailing edge discontinuities of the fundamental frequency contour, which increased accuracy in poor signal-to-noise (SNR) samples. The replicate correlator allowed detection of the stereotypical LF whale call with high accuracy (zero misses in a benchmark 24-hour sample) and low false-alarm rates (< 0.2% overall), even in very poor signal-to-noise conditions.

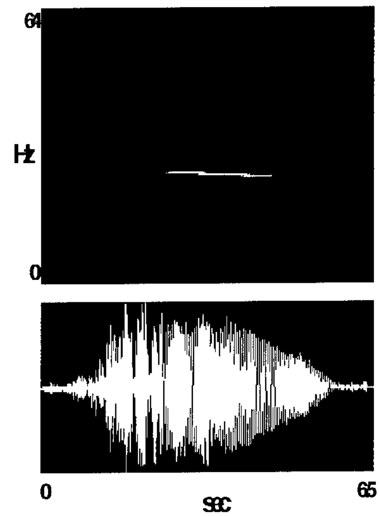

Figure 2. Replicate correlator function used to detect LF calls. The waveform is presented in the bottom panel, with window duration of 6.5 seconds and amplitude normalized. Choi-Williams spectrogram is presented in the top panel, with linear frequency ranging from 0 to 64 Hz and duration of 6.5 seconds.

RESULTS AND DISCUSSION

HUMPBACK WHALES

The methodology was sound. A total of 147 days was monitored from 18 July continuously through 11 December 1995, resulting in 220.5 hours of raw sound recordings. In 1996, sampling dates were 22 May to 10 June; 21 June to 6 August; and 21August to 7 October. A total of 117 days was monitored, resulting in 171 hours of raw sound recordings. No humpback whale song was heard throughout the sampling period in either 1995 or 1996.

No strong conclusions about the lack of humpback whale song can be made. The 1995 results are not surprising, given that sampling began late in the New Zealand migration season (Dawbin, 1966). However, sampling was conducted almost continuously during the traditional migration season in 1996. Song bouts may last for hours, and song can peak above 180 dB (Cato, 1984). Given these time and amplitude parameters, I am confident that the "acoustic net" was constructed properly with respect to "catching" singing humpback whales. The simple conclusion is that very few humpback whales pass through New Zealand waters. The research will complement developing studies of other Southern Hemisphere humpback whales and is a necessary step in developing a long-term monitoring program for this species in the Southwest Pacific.

LOW-FREQUENCY (LF) CALLS

Of particular note, one type of vocalization was observed intermittently across the 1995 and 1996 sampling seasons. This vocalization appears to be identical to that reported by Kibblewhite et al. in 1967, consisting of very low frequency frequency-modulated sweeps, typically lasting approximately 5 seconds. Figure 3 shows sample waveforms and Choi-Williams spectrograms. At first inspection, the most noticeable feature was differences in amplitude modulation among the calls. In contrast, spectrographic structure was fairly stereotypical, with an initial 1-second frequency-modulation (FM) sweep from approximately 50 to 24 Hz, followed by a near-constant frequency, 3-second component at 22 Hz. Figure 4 shows the average fundamental frequency contour extracted from 3,050 high-quality samples. The initial FM component was highly amplitude modulated in all occurrences. Amplitude modulation visible in the center-frequency (CF) tail of the call is likely due to multipath interference patterns caused by differences in depth of the calling animals.

In 1995, a seasonal peak of LF calls occurred in the month of October, early in the austral Spring. A total of 10,073 calls were detected in this period. Average received level (RL) was 98.39 (± 6.77) dB. Of the full sample, 2,058 calls had RL > 95 dB; the average duration of these high-quality samples was 4.65 (± 0.61) seconds. The left side of figure 5 shows the date and diel pattern of call occurrences. Notice that the calling was relatively evenly distributed across the month, but fairly strong crepuscular or nocturnal patterns were observed across the day. The majority of calls in the 1996 sample occurred across the months of July and August, austral midwinter. A total of 3,294 calls were detected in this period. The average RL was 87.0 (± 13.64) dB. Of the full sample, 992 calls had RL > 95 dB; the average duration of these high-quality calls was 4.24 (± 0.73) second. The right panel of figure 5 shows the date and diel pattern of 1996 call occurrences. In contrast to 1995, two peaks in calling were observed in mid-July and mid-August, but the distribution of calls across the day was relatively homogenous. Analysis of inter-call intervals was not conducted because I did not know how many individuals were present.

The species of the calling animal cannot be ascertained without visual confirmation of whales in the vicinity of the hydrophone. Although Bryde's whales (*Balaenoptera edeni*) were sighted frequently in the Great Barrier region, the spectral characteristics of the LF calls are different from calls recorded in the presence of Bryde's whales (Cummings et al., 1986). However, these vocalizations are in the frequency range reported for those of blue and fin whales (Cummings & Thompson, 1971; McDonald et al., 1995; Rivers, 1997; Stafford, 1997; Teranishi et al., 1997; Thompson et al., 1996). The duration and FM contour are very similar to blue whale "D" calls recorded in coastal North Pacific waters (Teranishi et al., 1997), and FM structure is reminiscent of brief FM sweeps ("S") reported by Thompson et al. (1996) in coastal Gulf of California waters. Interestingly, "D" calls have not been reported for pelagic North Pacific areas (Cummings & Thompson, 1994; McDonald et al., 1995; Stafford, 1997). The hydrophone used in the current study was also located in coastal waters.

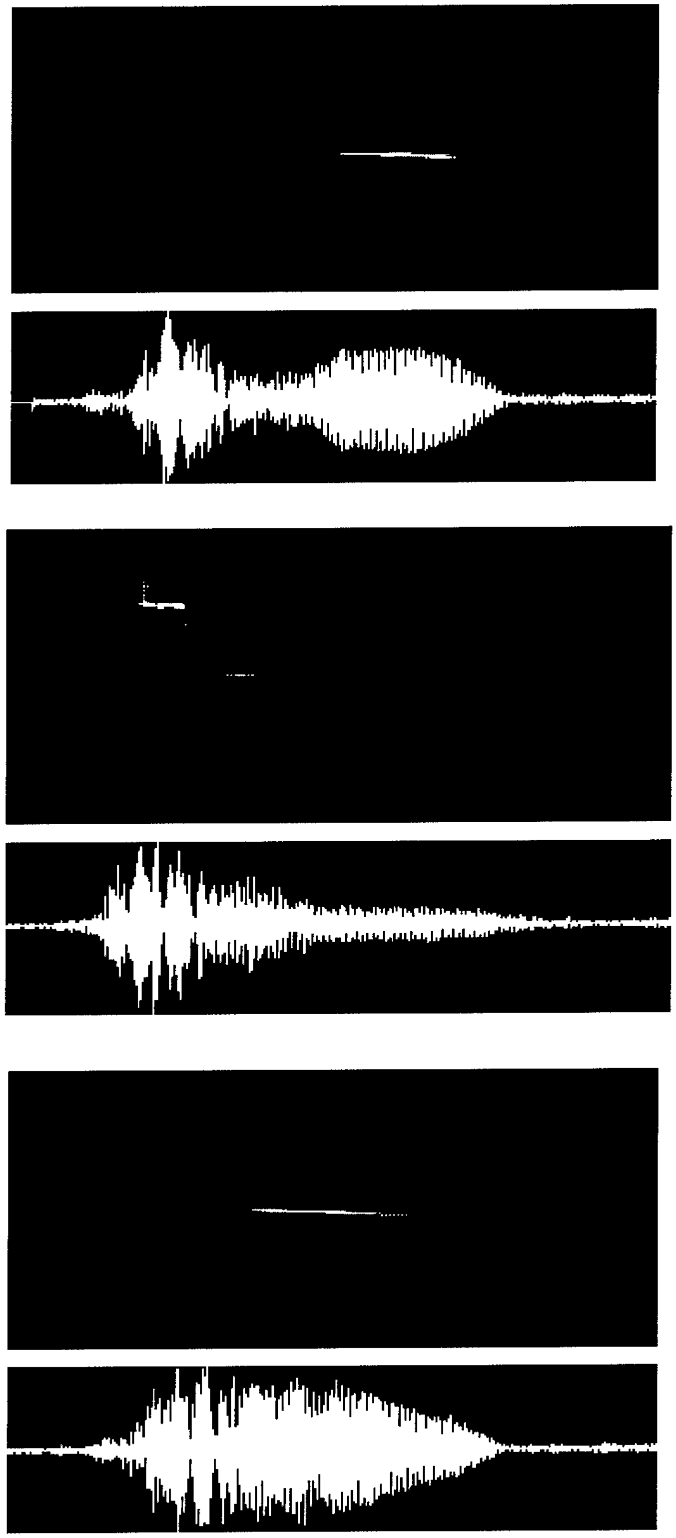

Figure 3. Sample variations in the envelopes of detected LF calls. Waveform and Choi-Williams spectrograms are presented as in figure 2. Note that although the amplitude envelope was variable, the frequency structure was relatively invariant.

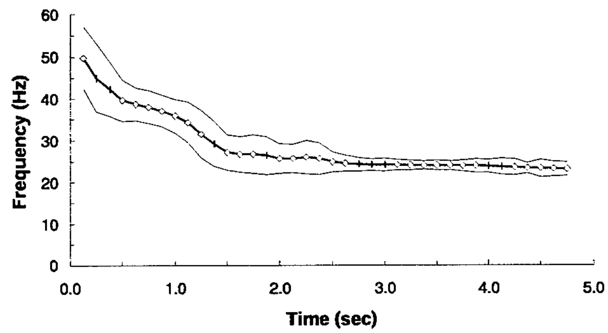

Figure 4. Mean and standard deviation of the fundamental frequency contour of LF calls.

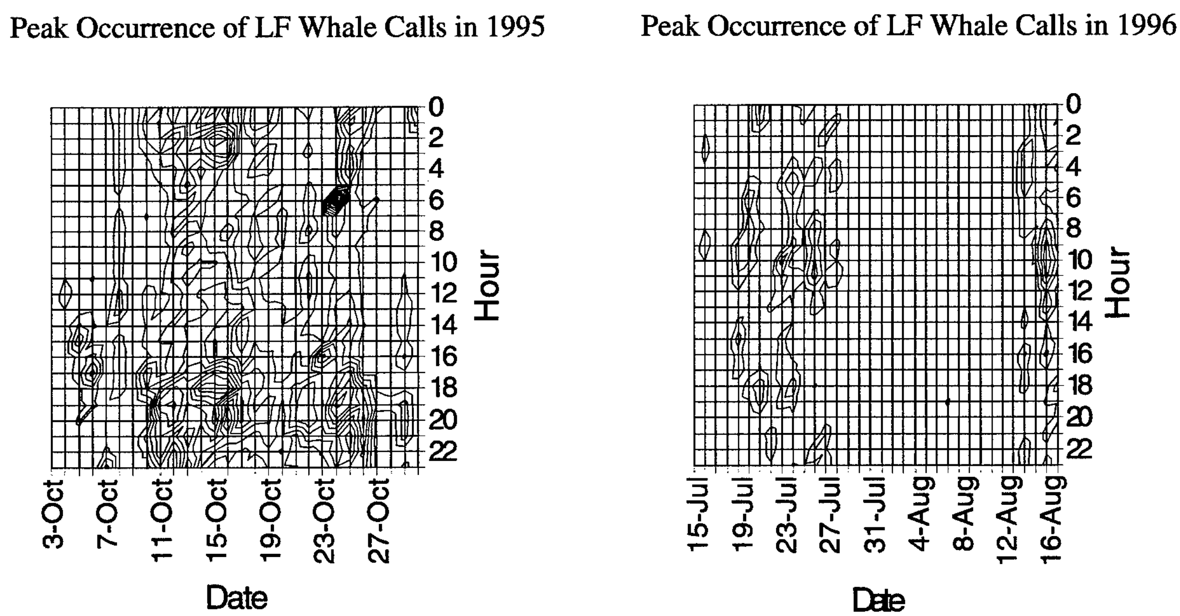

Figure 5. Daily and seasonal count of LF calls in 1995 and 1996 sampling periods. Contours are spaced every 10 counts.

During the peak calling periods of 1995 and 1996, reliable sightings of blue whales were made in the Bay of Plenty, northwest of East Cape. East Cape is approximately 310 km from Great Barrier Island as the crow flies, as figure 1 shows. Peak RL was estimated to be 124 dB, extrapolated from 12 clipped samples. If these calls were produced by blue whales, peak source levels can be assumed to have been approximately 180 dB re 1 µPa at 1 m (Clark, 1986). A simple estimated distance to the source may be bracketed using cylindrical propagation (10logR) and hybrid propagation (15logR). This places a 180-dB source between 5.4 and 398.1 km from the monitoring hydrophone, given a RL of 124 dB. This is consistent with the source of the LF calls being in the Bay of Plenty region.

AUTOMATED MONITORING METHODOLOGY

In this report I describe the results of an initial study using automated acoustic monitoring of New Zealand waters for the presence of singing humpback whales. The automated scan sampling and call detection techniques described in this paper may be integrated in future studies. The replicate correlator allowed detection of the stereotypical LF whale call with high accuracy (zero misses in a benchmark 24-hour sample) and low false-alarm rates (< 0.2% overall), even in very poor signal-to-noise conditions. Other baleen whale vocalizations, such as blue whale "A" and "B" calls and fin whale pulses are stereotypical (Clark, 1986; Cummings & Thompson, 1971; McDonald et al., 1995; Rivers, 1997; Stafford, 1997; Teranishi et al., 1997; Thompson et al., 1996). These vocalizations have been detected and logged using matched filters (Stafford, 1995). At the low sampling rates used to digitize baleen whale vocalizations, the "smart trigger" could be placed in the data-sampling stream and vocalizations could be detected and logged in real time. Acoustic monitoring of whale abundance and distribution is a viable methodology that is not as limited by weather, light, or mobility conditions as are vessel transect surveys. Such acoustic survey research will complement studies of populations and species of cetaceans wherever acoustic assets are available, and this research is a necessary step in developing a long-term monitoring program for endangered and threatened marine mammals.

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APPENDIX A
PASCAL CODE FOR SAMPLING SCHEDULE

```
{M 16384,0,0}
program run;
{GBI sample and save controller}
uses dos,crt;
const
        comf:string='c:\command.com';
        datadirectory='c:\gbidat\';
        key:char='';
        tapechanged:boolean=true;
        donemessage:boolean=false;
        readyforsample:boolean=true;
        nocursor=$2000;
        oncursor=$607;
var
        h,m,s,ss,mtot:word;
        w:aray[1.4] of word;
        wday:word;

procedure setcursormode(cursortype:word);
        var regs:registers;
        begin
                regs.ah:=1;
                regs.cx:=cursortype;
                intr($10,regs);
end; [setcursormode]

procedure bleep;
        var i:integer;
        begin
                for I:=1 to 20 do
                begin sound(350+(i mod5)*50);
                        delay(30);
```

```
        end;
        nosound;
end; {bleep}

procedure checkkey;
        begin if keypressed then
                begin key:=readkey;
                        if key=#0 then key:=readkey;
                end;
        case key of
        'y','Y':begin tapechanged:=true;
                gotoxy(1,25);
                clreol
                end;
        end;
end; {checkkey}

procedure newname(var s:string);
{create new file name}
        var  i:integer;
                s1:string[2];
        begin w[3]:=h;w[4]:=m;
                s:=datadirectory;
                for i:=1 to 4 do
                begin str(w[i],s1);
                        if length(s1)=1 then s1='0'+s1;
                        s:=s+s1;
        end;
end; {newname}

procedure writemessage;
{write message once every 10 secs}
        var  i:integer;
        begin if s mod 10<>0 then
                begin donemessage:=false;
                        exit;
        end;
```

```
        if donemessage then exit;
        gotoxy(1,25);clreol;i:=0;                    {only write message if not about to sample}
        i:=90-mtot mod 90;
        if i>=2 then
        begin
                {exec(comf,'/c\sbpub\sbplay 10000\subpub\tape.tlk');}
                write('Please change the tape, ',i,' min to next sample.');
                write('Type "y" when done');
        end
        else
                write('Tape needs changing, please wait for current sample');
                donemessage:=true;
end;{writemessage}

procedure waittime;
{wait for next sample and check if tape needs changing}
(nb. this is the only place where time & date are updated}
        var  ww:word;
        begin key:='';
                repeat
                gettime(h,m,s,ss); {get date & time}
                get date(ww,w[1],w[2],wday);
                if h=24 then h:=0;mtot:=h*60+m;         {total minutes today}
                if wday=0 then tapechanged:=false;      {reset for tape change}
                checkkey;                               {check for keypress}
                if not tapechanged
                        and (wday=1) and (h>7)          {bleep after 7 am monday}
                        then writemessage;
                if (tapechanged) or (wday=0) or (wday=1)
                        then readyforsample:=true;      {reset for next sample}
                gotoxy(random(79)+1,random(23)+1); {screensaver}
                setcursormode(nocursor);
                if random(100)=0 then write('*')
                        else write('');
                until (key=#27) or readyforsample and {exit for next sample}
                        (mtot mod 90=0);
        clrscr;
```

```
end; {waittime}

var
        name:string;
        ww:word;
begin
        clrscr;
        comf:=getenv('COMSPEC');
        repeat
waittime;                                               {wait till sample time}
if key<>#27 then
begin                                                   {sample & copy to tape}
        newname(name);                                  {generate name for file}
        writeln('sampling',name);                       {sample to data file}
        exec(comf,'/c sbrecord 300 5000 sample.raw');
        exec(comf,'/c pkzip'+name+'sample.raw');        {zip data file}
        if (h=1) and (m<50) then                        {save to tape at 1am}
        begin
                writeln('saving files to tape');
                exec (comf,'/c qbackup copydata/a/tc');         {backup to tape}
                exec(comf,'/c del'+datadirectory+'*.zip');      {delete data files}
        end;
        delay(1000);readyforsample:=false;
end;
until key=#27;
setcursormode(oncursor);
end.
```

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13. ABSTRACT *(Maximum 200 words)*

Historically, some Southern Hemisphere Area V (130°E to 170°W) humpback whales (*Megaptera novaeangliae)* migrated from Antarctic feeding sites to wintering sites off eastern Australia and the southwestern Pacific through New Zealand waters. During winter months, males appear to advertise their presence by producing lengthy, loud songs, and the presence of singing whales is a reliable indicator of a migratory route. Today, humpbacks are sighted only occasionally in New Zealand waters. Because the number of humpback whales passing through New Zealand waters is extremely low, the probability of visual encounters is limited relative to the probability of acoustic detection, at least for singers. This study describes the results of acoustic monitoring of New Zealand waters for the presence of singing humpback whales. A low-cost, off-the-shelf computer system and shareware was used to automate the monitoring process. A total of 147 days were monitored from 18 July through 11 December 1995, and 117 days from 22 May through 7 October 1996. No singing humpback whales were heard in either year throughout the sampling period. However, a 5-second FM downsweep from 50 to 22 Hz was heard in both years, identical to that reported by Kibblewhite et al. in 1967. More than 14,000 of these calls were detected, extracted, and measured using a simple replicate correlator in real time. Although the species is unknown, the joint time-frequency structure of these calls is very similar to blue whale "D" calls reported in coastal North Pacific waters. The automated scan sampling and call detection techniques described may be integrated and applied to monitoring for vocalizing whales in future studies.

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